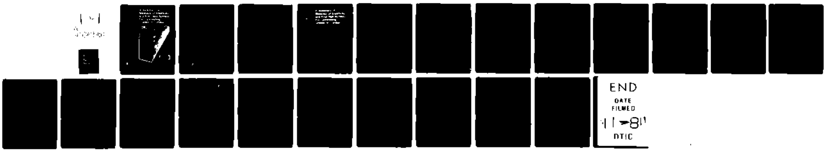
AD-A106 561 FOREST PRODUCTS LAB MADISON WI F/G 11/12
A SUMMARY OF MODULUS OF ELASTICITY AND KNOT SIZE SURVEYS FOR LA--ETC(U)
JUN 81 R W WOLFE, R C MOODY
UNCLASSIFIED FSGTR-FPL-31 NL



United States
Department of
Agriculture

Forest Service

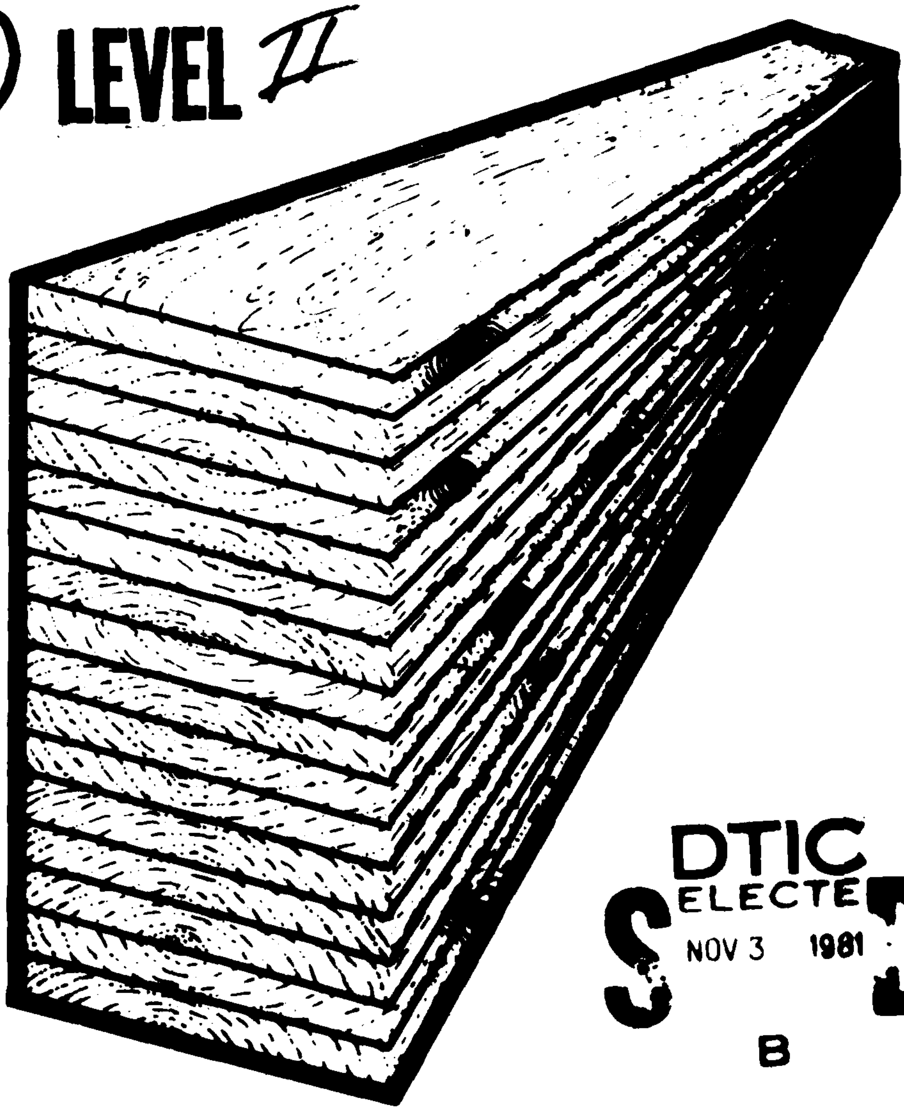
Forest
Products
Laboratory

General
Technical
Report
FPL-31

A Summary of Modulus of Elasticity and Knot Size Surveys For Laminating Grades of Lumber

(12) LEVEL II

AD A106561



DTIC
ELECTE
NOV 3 1981
S D
B

DTIC FILE COPY

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

81 11 03 061

Abstract

A summary of modulus of elasticity (MOE) and knot data is presented for grades of lumber commonly used to manufacture glued-laminated (glulam) timber by the laminating industry. Tabulated values represent 30 different studies covering a time span of over 16 years. Statistical estimates of average and near-maximum knot sizes as well as mean and coefficient of variation for MOE are given. Modulus of elasticity values are compared with those published for design.

Results will be helpful to organizations preparing and evaluating specifications for glulam timber

L4-2-1, GR4-7-2-3

U.S. Forest Products Laboratory

A summary of modulus of elasticity and knot size surveys for laminating grades of lumber, by R. W. Wolfe and R. C. Moody, Madison, Wis., FPL 1981.

20 p. (USDA For. Serv. Gen. Tech. Rep. FPL-31).

A summary of modulus of elasticity (MOE) and knot data is presented for grades of lumber commonly used to manufacture glued-laminated (glulam) timber by laminating industry, statistical estimates of average and near maximum knot sizes as well as mean and coefficient of variation for MOE are given. MOE values are compared with those published for design.

Keywords: glulam, modulus of elasticity, knot, continuous lumber tester (CLT), E-computer.

United States
Department of
Agriculture

Forest Service

Forest
Products
Laboratory[1]

General
Technical
Report
FPL-31

June 1981

A Summary of Modulus of Elasticity and Knot Size Surveys For Laminating Grades of Lumber.

By
R. W. WOLFE, Technologist
and
R. C. MOODY, Engineer

Introduction

For many years, USDA Technical Bulletin No. 1069 *(6)*[2] has provided the basis for the manufacture and design of glued-laminated (glulam) timber. ASTM Standard D 3737 *(5)*, incorporates many of the concepts for establishing stresses from Technical Bulletin No. 1069, as well as significant modifications in many areas where new data are available. With ASTM D 3737, bending stresses for glulam combinations can be determined by using the lumber properties which are a clear wood design stress in bending for the species, and both modulus of elasticity (MOE) and knot properties for the grade. Clear wood design stress values for several species are listed in ASTM D 3737 and procedures for obtaining these stresses for other species are also given. The other two factors, MOE and knot properties, may be obtained from surveys on lumber used for laminating. The purpose of this report is to summarize MOE and knot data from lumber that was a part of research studies conducted between 1963 and 1979. Such data will be helpful in establishing specifications for glulam timber.

[1] Maintained at Madison, Wis. in cooperation with the University of Wisconsin.
[2] Italicized numbers in parentheses refer to literature cited at end of this report.

Material

Most glulam timber used in the United States is made of either Douglas-fir or southern pine lumber. In addition, the hem-fir grouping of lumber also provides a significant volume of material. Thus, the primary emphasis of this report will be on these three species groups. However, where significant amounts of lumber from other species groups were used in a research study of glulam timber, they are also listed in appendix II. Further details of the material for each study are given in appendix I.

Methods of Determining Properties

Different techniques were used to measure MOE and knot sizes in the many different sources of data. Also, techniques used to measure moisture content and specific gravity, two properties which are helpful in interpreting MOE data, often differed.

Modulus of Elasticity (MOE)

Methods used to obtain MOE data may be placed in two general categories— machine measurement and static test. The methods used to measure MOE values for most of the lumber were techniques which minimized the influence of shear deflections.

Machine Measurement.—The two MOE measuring methods used included the E-computer and the continuous lumber tester (CLT). The E-computer bases the MOE determination on the natural frequency of vibration of a piece tested flatwise over a span of nearly its full length. The CLT is a commercial stress-grading machine which classifies lumber into different MOE categories based on both minimum and average MOE measured over a short span at increments along the length. It does not give specific data for each piece; and no specific MOE data were obtained by the CLT. Thus all data for machine measurement of MOE are from an E-computer.

Static Test.—Variations in methods of measuring MOE by static tests make the comparison of different data difficult. In some of the data sources included in this study, the MOE measurements were made by applying a concentrated load near the center of a span between two simple supports and measuring the displacement. Conventional engineering analysis was then used to determine MOE. In other cases, the slope of the linear portion of the load-deflection curve was determined for a static test to failure. Variations in specimen orientation and span-to-depth ratio may also lead to problems in comparing data from different sources. Thus, although data are included, caution is advised in using it for comparison purposes.

Knot Measurement Methods

Four different techniques have been used to measure knot sizes. These techniques are referred to as the displacement, worst face, random surface, and weighted surface methods.

Displacement Method.—The method most commonly used for recent knot surveys conducted by the FPL has been termed the displacement technique. It involves measuring a knot's width (dimension parallel to the width of the lumber) on both faces of a piece of lumber and taking an average value as an estimate of the projected area occupied by the knot.

Worst Face Method.—The worst face method records the largest width for a given knot or the width on the bark side of the piece.

Random Surface Method.—The worst face method adds a bias to the high side of knot-size data. By alternating bark side-pith side or randomly selecting the surface on which knots are to be measured, this bias may be decreased or possibly eliminated.

Weighted Surface Method.—This method is sometimes used on lumber designated for beam manufacture. Knot diameters are measured on the surface of the lamination which will be farthest from the neutral axis of the beam. It likely corresponds closely with the random surface method.

Two of the studies noted in appendix II (sources 23 and 24) were designed to obtain knot data on grades of lumber used in laminating and thus represent the best estimate of knot properties. More details on the sampling procedures are given in appendix I.

Moisture Content

Field measurements of moisture content were made using commercial moisture meters which rely on the change in the electrical properties of wood with a change in moisture content.

Determination of Specific Gravity

In many cases, specific gravity was estimated based on the approximate ovendry weight and volume at time of test. However, in some cases samples were taken for specific gravity determination by methods described in ASTM D 2395 *(2)*.

Analysis Techniques

Thirty separate studies were reviewed to obtain the MOE and knot data tabulated in appendix II. An attempt was made to compare these studies on a common basis in order to derive distribution parameters which are representative of the population.

Modulus of Elasticity

Values for mean and coefficient of variation (COV) for MOE were obtained from 18 of the studies reviewed. In each case, values were adjusted to 12 percent moisture content using procedures given in ASTM D 2915 *(4)*. If individual values of MOE and moisture content were available, a new COV was derived for the 12 percent values, otherwise, COV was assumed to be unchanged. No adjustments were made for differences in span-depth ratio.

Douglas-fir and southern pine were the only species for which the number of studies, consisting of over 70 tests, were sufficient to warrant statistical consideration in the derivation of representative values for mean, COV, and a 90 percent confidence range on the mean.

Knot Sizes

Knot data were reported in the form of knot maps listing coordinates for each knot in each piece of lumber. The three coordinates included the distance from a zero end to the center of the knot and distances from a zero edge to the top and bottom borders of the knot. A computer program, which followed procedures given in USDA Technical Bulletin No. 1069, was used to interpret these knot maps. The program assumed all knots to be cylindrical in shape with a diameter equal to the knot width and a length equal and parallel to the lumber thickness. Knot areas (length x width) in each 1-foot interval were projected onto the lumber cross section (fig. 1). The lumber cross section area occupied by projected knots was then stored as the "sum of knots." This summation was calculated for 1-foot intervals taken at 0.2-foot increments along the length. Intervals measured within the last foot of each piece overlapped the first foot so that the full length of each piece of lumber was included.

The computer program determined the total number of 1-foot sections for various sums of knot sizes and

Figure 1.—Assumed cross-sectional area of knots in 1-foot interval of unit depth projected on end of the interval.

(M 148 [illegible])

prepared a listing of the number of 1-foot sections with each knot size. The average sum of knot sizes was determined for the various grades. Also from this listing of data, cumulative distribution functions were plotted on normal probability paper. A normal distribution appears linear on such graph paper and previous data have agreed reasonably well with a truncated normal distribution. The point corresponding to the 1/2 percent upper exclusion limit (0.995 percentile) provided an estimate of the near-maximum sum of knot sizes for the grade.

Data Presentation

Tables 1 and 2 summarize the most significant MOE and knot data from surveys covered in this study. Also shown in table 1 are the long span design values for various grades published by the American Institute of Timber Construction (AITC) that were used as a basis for their 1979 specifications.

Data presented in table 2 were taken from two knot surveys (sources 23 and 24 listed in appendix II).

Values obtained from individual studies are tabulated in appendix II. Tables II-1 through II-3 contain information for visual grades and tables II-4 to II-7 present knot distribution data for E-rated or machine-stress-rated (MSR) lumber.

Discussion

Average MOE for the 4 grades of Douglas-fir (table 1) exceeds the long span design value by between 2 and 12 percent. The average MOE of the southern pine lumber was close to the design values, with 3 of the 4 grades averaging within 2 percent of the long span design value. The fourth group of southern pine, No. 2 MG grade, was 7 percent less than the design value. The expected trend for decreasing MOE with decreasing grades is apparent but there appears to be no effect of grade on the coefficient of variation in MOE.

The value of the average projected knot size for Douglas-fir laminating grades of lumber, reported in table 2, is essentially the same as that reported in the last major study of knot sizes (source 1, appendix I). However, corresponding values for southern pine are slightly larger for the No. 1 grade and significantly larger for No. 2 *(7)*. This is probably due to interim changes in the grade descriptions. In both cases, statistically determined near-maximum or upper-exclusion values have increased.

Knot sizes for the joist and plank grades of Douglas-fir were expected to be comparable to those of the laminating grades *(8, 9)* on the basis of maximum knots permitted in the two grading systems. Select structural (SS) had smaller knots than L1; No. 1 and No. 2 are similar to L2; and No. 3 is similar to L3. There was only a small difference between No. 1 and No. 2 which would question the advisability of using both grades. Rather, No. 2 could contain both grades with little effect on the beam properties.

Table 1.—Summary of modulus of elasticity data for samples of Douglas-fir and southern pine containing more than 70 pieces

Grade	Number of pieces of lumber	Modulus of elasticity[1] Mean	Coefficient of variation[2]	90 Percent confidence interval on mean	Long span values used as basis for design[3]	Ratio of mean to long span design basis
		Million lb/in.[2]	Pct	Million lb/in.[2]		
DOUGLAS-FIR						
L1	1,934	2.23	17.5	2.18-2.30	2.1	1.06
L2D	300	2.13	19.4	1.95-2.31	1.9	1.12
L2	1,108	1.83	16.8	1.74-1.92	1.8	1.02
L3	2,273	1.68	20.2	1.56-1.72	1.6	1.05
SOUTHERN PINE						
No. 1D	971	1.95	18.2	1.86-2.06	2.0	.98
No. 1MG	301	1.83	21.7	1.63-2.03	1.8	1.02
No. 2D	1,886	1.76	18.9	1.71-1.81	1.8	.98
No. 2MG	2.386	1.40	22.4	1.27-1.53	1.5	.93

[1] All data adjusted to 12 pct moisture content with ASTM D 2915.
[2] Coefficient of variation = standard deviation/mean.
[3] Published by the American Institute of Timber Construction, Determination of Design Values for Structural Glued Laminated Timber, AITC 117-79, table 4-1.

Table 2.—Summary of knot data for laminating grades[1]

Grade	Linear feet surveyed	Average knot size	Near-maximum knot size	k[2]
		Pct	Pct	Pct
DOUGLAS-FIR LAMINATING GRADES BY DENSITY CLASSIFICATION				
L1C	2,870	7.4	39.8	32.4
L1 (dense)	2,910	6.4	38.7	32.3
L2M	2,980	11.0	50.2	39.2
L2D	2,950	9.5	46.7	37.2
L3	2,940	11.6	58.0	46.4
DOUGLAS-FIR GRADES COMBINED DISREGARDING DENSITY				
L1	5,780	6.9	39.3	32.4
L2	5,910	10.3	48.4	38.1
DOUGLAS-FIR JOISTS AND PLANK GRADE				
SS	4,150	5.6	36.3	30.7
N1	4,300	9.8	47.1	37.3
N2	4,300	10.8	51.6	40.7
N3	4,150	10.4	58.7	48.3
SOUTHERN PINE GRADES BY DENSITY CLASSIFICATION				
No. 1MG	2,730	3.4	38.0	34.6
No. 1D	2,690	3.2	31.6	28.4
No. 2MG	2,600	7.7	43.4	35.7
No. 2D	2,620	8.1	52.0	43.9
SOUTHERN PINE GRADES COMBINED DISREGARDING DENSITY				
No. 1	5,420	3.3	35.6	32.3
No. 2	5,220	7.9	51.5	43.6

[1] Data from sources 23 and 24 listed in appendix II.
[2] Difference between the near-maximum and average sum of knot sizes.

Literature Cited

1. American Society for Testing and Materials.
   1978. Standard static tests of timbers in structural sizes. ASTM D 198. Philadelphia, Pa.

2. American Society for Testing and Materials.
   1978. Standard specific gravity of wood and wood base materials. ASTM D 2395. Philadelphia, Pa.

3. American Society for Testing and Materials.
   1978. Standard establishing clear wood strength values. ASTM D 2555. Philadelphia, Pa.

4. American Society for Testing and Materials.
   1978. Standard evaluating allowable properties for grades of structural lumber. ASTM D 2915. Philadelphia, Pa.

5. American Society for Testing and Materials.
   1978. Standard establishing stresses for structural glued-laminated (glulam) manufactured from visually graded lumber. ASTM D 3737. Philadelphia, Pa.

6. Freas, A. D., and M. L. Selbo.
   1954. Fabrication and design of glued-laminated wood structural members. USDA Tech. Bull. No. 1069.

7. Southern Pine Inspection Bureau.
   1970. Standard grading rules for southern pine lumber. SPIB— Pensacola, Fla.

8. West Coast Lumber Inspection Bureau.
   1970. Standard grading rules for west coast lumber WCLIB—Portland, Oreg.

9. Western Wood Products Association.
   1972. Grading rules for western lumber. 2nd ed. WWPA, Portland, Oreg.

APPENDIX I

Sources of Data

This appendix provides a reference to data sources cited in appendix II. The sources are listed in chronological order along with a brief description of the data collected. The primary listings following each source number identify the species of lumber considered in the study. If the research results which produced the data are available in the form of a published report, a complete reference is also provided. For those sources labeled unpublished, the raw data are on file at the Forest Products Laboratory.

Source 1: Early FPL-Industry Surveys

Knot data were collected for Douglas-fir and southern pine during the 1950's and early 1960's by lumber associations in the United States. These data, although never published, were used in preparing specifications for glued-laminated timber prior to 1976.

Little information is available regarding sample sizes, methods of selection or knot measuring technique for these surveys. Information on file at FPL suggests that, in early surveys, industry representatives measured the widths of knots on the worst face, i.e., maximum dimension. Conversation with a representative who participated in one survey indicated that the random surface method was also used, i.e., the widths of knots were measured on the bark side of one piece and the pith side of the next.

Source 2: Canadian Western Hemlock
Littleford, T. W.
1963. Knot frequency study of laminating grades for western hemlock. Canada Dep. of For. Publ. No. 1009.

Knot data were collected for four Canadian laminating grades of western hemlock. The total sample of 360 pieces was collected from four large west coast saw mills and included 90 pieces of each grade (A, B, C, and D). For each grade, 45 pieces were of nominal 2 x 6 and 45 were 2 x 10. The knots were measured using the "displacement technique" and sizes were recorded to the nearest 1/4 inch.

Sources 3-5: Southern Pine Lumber Studies
Doyle, D. V., and L. J. Markwardt.
1966. Properties of southern pine in relation to strength grading of dimension lumber. U.S. Dep. Agric. For. Serv. Res. Pap. FPL 64. For. Prod. Lab., Madison, Wis.

Doyle, D. V., and L. J. Markwardt.
1967. Tension parallel-to-grain properties of southern pine dimension lumber. U.S. Dep. Agric. For. Serv. Res. Pap. FPL 84. For. Prod. Lab., Madison, Wis.

Doyle D. V.
1968. Properties of No. 2 dense kiln-dried southern pine dimension lumber. USDA For. Serv. Res. Pap. FPL 96. For. Prod. Lab., Madison, Wis.

These 3 studies included modulus of elasticity (MOE) data for over 1,500 pieces of southern pine lumber obtained from mills in the 10 major southern pine producing states. All lumber was graded as No. 1, No. 2, or No. 3 according to the 1963 SPIB rules. Lumber sizes included 2 by 4, 2 by 8, and 2 by 10. Modulus of elasticity values determined by bending test, tension test, or compression test are included.

The edgewise static bending test for determination of edge MOE, followed the ASTM standard D-198 *(1)* with provision for buckling restraint. Flatwise bending stiffness was determined by applying weights at two points and measuring the increase in deflection. For the compression MOE measurement, special methods were used to prevent buckling. Deformation was measured with dial gages over a gage length equal to the nominal length of the specimen minus 6 inches.

Knot size data from these studies were not included.

Source 6: Canadian Douglas-fir
Littleford, T. W.
1967. Tensile strength and modulus of elasticity of machine graded 2 by 6 Douglas-fir. West. For. Prod. Lab. of Can. VP-X-12.

This lumber sample consisted of 320 pieces of 2 by 6 lumber comprising 5 Canadian visual grades.

Lumber was obtained from three sawmills and one laminating plant in British Columbia. Four visual grades were regraded on a CLT-1 mechanical stress-grading machine using 1965 WWPA rules. Modulus of elasticity in flexure was determined by loading at 1/5 points over a span of 115.5 inches. Modulus of elasticity in tension was determined by measuring tensile deformation over a 108-inch gage length.

Knot size data from this study were not included.

Source 7: FPL Beam Study 1969
Bohannan, B., and R. C. Moody
1969. Large glued-laminated timber beams with two grades of tension laminations. USDA For. Serv. Res. Pap. FPL 113. For. Prod. Lab., Madison, Wis.

Two by 6 lumber for this study was in 2 species groups—coast region Douglas-fir and southern pine.

Douglas-fir was purchased in the Portland, Oregon area and was selected from production of a laminating plant over a 5 consecutive-day period. The southern pine lumber was obtained from five different lumber shipments received by a commercial laminating plant—sources represented four suppliers in several different states throughout the South.

Two by 10 lumber was also included in this study and it was obtained in somewhat similar fashion except that the Douglas-fir lumber was selected in 2 days while the southern pine was from 2 shipments.

Modulus of elasticity was determined with an E-computer. Knot data were also collected using the weighted face method.

Source 8: OSU Beam Study 1969
Johnson, J.
1969. Flexural tests of large glued-laminated beams made of nondestructively tested lumber. Oreg. State Univ. Rep. T-26.

Lumber for this study was in two species groups—Douglas-fir and hem-fir, the latter group consisting of western hemlock and several species of fir. All lumber was 2 by 6.

Modulus of elasticity values were determined using an E-computer and knots were measured within the center 20 feet on each 40-foot lamination after end jointing. The weighted face method was used to measure knot size.

Source 9: FPL Southern Pine
Moody, R. C.
1970. Tensile strength of finger joints in pith-associated and non-pith-associated southern pine 2 by 6's. USDA For. Serv. Res. Pap. FPL 138. For. Prod. Lab., Madison, Wis.

Southern pine 2 by 6 dimension lumber was selected to meet or exceed the AITC 301-67 tension lam grade. The sample consisted of 12-foot material, selected and graded by personnel of the laminating plant where it was obtained. No special effort was made to represent any particular supplier or region. Modulus of elasticity values were determined from load-deformation plots obtained during tension testing.

Source 10: FPL Beam Study 1970
Moody, R. C., and B. Bohannan.
1970. Large glued-laminated beams with AITC 301A-69 grade tension laminations. USDA For. Serv. Res. Pap. FPL 146. For. Prod. Lab., Madison, Wis.

Three species and groups of lumber are represented in this study—coast region Douglas-fir, interior North region Douglas-fir, and southern pine. All material was 2 by 6. The coast region Douglas-fir was obtained at a laminating plant in the Portland, Oregon area. The interior North region Douglas-fir was obtained from a laminating plant in the Billings, Mont. area. The southern pine was obtained from shipments by two different suppliers at a laminating plant and represented two different states.

Each piece of lumber was regraded, weighed, and checked for moisture content. No modulus of elasticity data are collected for the lumber. After finger jointing, each lamination was mapped for knot and finger-joint location over the center 20 feet of the length. Knots were measured using the weighted surface method.

The lumber sample included southern pine graded according to SPIB rules *(7)*, coast region Douglas-fir (WCLIB) *(8)*, and interior North region Douglas-fir (WWPA) *(9)*. The SL grades were used at the time by WWPA for classification of structural laminations. Grades SL1 through SL3 are roughly equivalent to L1 with varying restrictions for rate of growth, SL4 and SL5 correspond to L2 and L2D, and SL6 is the same as L3.

Source 11: Compression Study
Moody, R. C.
1970. One- and two-ply compression study. Unpublished FPL report.

This study includes four different grades of 2 x 6 material: two of coast region Douglas-fir (L2 and L3) and two of southern pine (No. 2MG and No. 3MG). The coast region Douglas-fir was obtained from Oregon or Washington. The southern pine was purchased from a mill in Texas.

Modulus of elasticity data for this material was measured using an E-computer. No knot data were obtained from this study.

Source 12: OSU Beam Study 1971
Johnson, J. W.
1971. Design and test of large glued-laminated beams made of nondestructively tested lumber. Oreg. State Univ. Rep. T-27.

The lumber used was in three species categories: southern pine, Douglas-fir, and hem-fir. All 2 x 6 lumber, which varied in length from 8 to 20 feet, was separated into MOE classes using the E-computer plus visual restrictions. After end jointing into 40-foot laminations, knots were mapped using the weighted surface method over the center 20 feet of the outer four compression and outer four tension laminations of each beam. In addition, knots were measured in all laminations for one beam out of each series of six.

Source 13: OSU Beam Study 1973
Johnson, J. W.
1973. Flexural tests of large glued-laminated beams made from visually graded hem-fir lumber. Oreg. State Univ. Rep. T-18.

The lumber included 2 by 6 western hemlock and white fir graded as laminating stock according to WWPA *(9)* and WCLIB *(8)* rules. Lengths varied from 12 to 16 feet.

It was purchased as 25 percent No. 3, 25 percent No. 2, and 50 percent No. 1 or better. The total sample was collected from five mills in Washington, Oregon, and California.

Modulus of Elasticity values were determined with an E-computer, and knot data were not included.

Source 14: Lodgepole Pine Knot Survey

This was a limited sample comprising 1,150 lineal feet of 2 by 6 L3 lodgepole pine lumber from the Bend, Oregon area. Lumber lengths included 100 8-foot, 37 14-foot, and 10 16-foot pieces. Knot sizes were measured and recorded by AITC representatives using the displacement technique.

Source 15: Eastern Spruce Knot Data

Knot data for three structural grades of 2 by 6 eastern spruce were collected by representatives of the University of Maine as part of a feasibility study of using eastern spruce for glulam timber. The displacement technique was used to measure knot size and no modulus of elasticity data were obtained.

Source 16: FPL Beam Study 1974
Moody, R. C.
1974. Flexural strength of glued-laminated timber beams containing coarse-grain southern pine lumber. USDA For. Serv. Res. Pap. FPL 222. For. Prod. Lab., Madison, Wis.

Material used in this study falls into three density/rate-of-growth classifications from the 1970 SPIB rules *(7)*: dense (D), medium grain (MG), and coarse grain (CG) or open grain. Three SPIB visual grades (No. 1, No. 2, and No. 3) as well as 2 AITC tension lamination grades (301-20 and 301-24) of 2 by 6 southern pine were obtained from 11 different mills in Alabama, Arkansas, Louisiana, Mississippi, and Texas. One mill in Texas supplied most of the No. 3CG material.

Specific gravity and MOE were obtained from measurements taken with an E-computer. After finger jointing, knots were measured within the center 20 feet of each 40-foot-long lamination. The displacement method was used to measure knots for tension laminations and the weighted surface method was used for the rest of the sample.

Source 17: FPL Beam Study 1974
Moody, R. C.
1974. Design criteria for large structural glued-laminated timber beams using mixed species of visually graded lumber. USDA For. Serv. Res. Pap. FPL 236. For. Prod. Lab., Madison, Wis.

Coast region Douglas-fir from the Oregon-Washington area and lodgepole pine from the Bend, Oregon area were used in this study. Specific gravity and MOE were determined from data obtained using an E-computer. After finger jointing the 2 by 6 lumber to 41-foot-long laminations, knot sizes and finger-joint locations were measured over the center half length. For all except the tension laminations, the weighted surface knot measurement method was used. The displacement method was used for tension laminations.

Source 18: Koppers Southern Pine Data

These data collected by Koppers Company consist of two visual grades (No. 1D and No. 2MG) of southern pine and one tension lamination grade (301-24) collected at one of their laminating plants. Knot size for the 2 by 6 lumber was determined using the weighted surface method, and no modulus of elasticity data were obtained.

Source 19: Laminated-Veneer Tension Lamination Study
Braun, M. D., and R. C. Moody.
1977. Bending strength of small glulam beams with a laminated-veneer tension lamination. For Prod. J. 27(11):46-50.

Douglas-fir 2 by 4 lumber, from Washington or Oregon, comprised 3 laminating grades (WCLIB). The MOE and weight of each piece was determined following finger jointing into 20-foot lengths using an E-computer. Knot sizes were measured over the middle 10 feet of each piece using the weighted face technique.

Source 20: Weyerhaeuser Tension Study
Unpublished data on the tensile strength of one-, two-, and three-lamination members of 2 by 6 Douglas-fir. Study conducted by Weyerhaeuser Co. (1970).

The test sample consisted of five grades of Douglas-fir, including two AITC tension lamination grades, selected from laminating stock during 1969 and 1970. Material was selected so that members could be fabricated from either minimum-quality stock in each grade or average-quality stock. One series was selected for maximum strength-reducing features permitted while another series was randomly selected from a large representative population. All material was grade checked by a WWPA grader.

As there appeared to be no significant difference between the MOE values for the random and low-line series, they were combined for this report. Knot data were not included for this study.

Source 21: AITC Joists and Plank

These data were collected as part of a preliminary study by AITC to characterize lumber grades having potential for use in the laminating industry in 1975. AITC representatives measured knots using the displacement technique in 2 by 6 Douglas-fir in each of 3 visual grades. The lumber was obtained from the Boise, Idaho area and consisted of joist and plank grades (No. 1, No. 2, and No. 3) of Douglas-fir.

Source 22: AITC Hem-fir Knot Data

This knot survey was conducted by AITC personnel. The lumber sample was selected at one mill by a WCLIB representative and consisted of samples (2 by 6 by 16 feet) in each of 2 machine stress rated grades. Knots were measured using the displacement technique.

Source 23: FPL/AITC Knot Survey of Laminating Grades
Moody, R. C.
1976. A survey of knots in laminating grades of Douglas-fir and southern pine lumber. Unnumbered FPL report.

This study was conducted over a 3-1/2-year period extending from mid-1972 to 1976 in order to develop representative knot data for laminating grades of Douglas-fir and southern pine. All data were collected by representatives of AITC, and the FPL provided broad sampling guidelines and analyzed the data to determine knot-size distribution parameters.

Both Douglas-fir and southern pine were included in this study. The sampling plan included 5 grades of 2 by 6 lumber in each of these species. Douglas-fir grades included L1, L1C, L2, L2D, and L3 as described by WCLIB *(8)* and WWPA *(9)*. Southern pine grades included No. 1D, No. 1, No. 2D, No. 2MG, and No. 3 as described by SPIB grading rules *(7)*. However, due to a lack of sufficient No. 3 southern pine material, this grade was not included in the analysis.

Material for each species was selected at laminating plants. For the Douglas-fir, 17 plants were represented. Nine plants were included in the southern pine survey. For each grade, the total sample consisted of 200 pieces collected during 40 sampling visits to the participating plants.

The knot sizes were measured using the displacement technique.

Source 24: FPL/AITC Douglas-fir Joist and Plank Grades

This study was conducted in 1976 to provide information regarding the feasibility of substituting "Joists and Planks" grades for laminating grades. The survey, conducted as a cooperative study between AITC and FPL, evaluated the knot properties of four Joist and Plank (J&P) grades of Douglas-fir. For each grade the sample was made up of 50 pieces of 2 by 6 lumber from each of the 5 mills located in Washington, Oregon, and northern California. The displacement method was used to measure knots.

Source 25: AITC Project 77C

The sample included L1 grade 2 by 6 Douglas-fir lumber ranging in length from 12 feet to 14 feet. The material was selected from production at a sawmill in Oregon in 1977. An E-computer was used to measure MOE and board weight. This study did not consider knot size properties.

Source 26: MSR Hem-fir

The lumber sample consisted of 4 grades of hem-fir which was estimated to be about 2/3 western hemlock. The material was from a single supplier in the Willamette Valley of Oregon in 1977. A continuous lumber tester (CLT-1) was used to classify the material into MOE classes. It was then visually graded and placed in machine stress-rated (MSR) grades by a WCLIB grader. Knots were measured over the full length of each piece by AITC representatives using the displacement method. Individual modulus of elasticity values were not determined.

Source 27: FPL Beam Study 1977
Moody, R. C.
1977. Improved utilization of lumber in glued laminated beams. USDA For. Serv. Res. Pap. FPL 292. For. Prod. Lab., Madison, Wis.

Several species of 2 by 4 dimension lumber are included in this study. Visually graded Douglas-fir was obtained from northern California. Visually graded hem-fir lumber was obtained from the Boise, Idaho area. Mechanically stress-rated hem-fir and Douglas-fir were obtained from western Oregon. Lodgepole pine lumber was obtained from eastern Oregon and Engelmann spruce lumber from Colorado. The southern pine lumber was selected from material available at a commercial laminating plant and its source was not determined.

For most grades, weight and MOE were determined prior to finger jointing using an E-computer. However, the L3 and No. 3 Douglas-fir and No. 2MG southern pine were evaluated in 20.3-foot-long finger-jointed laminations. The weighted face method was used to measure knot sizes.

Source 28: Vertically Laminated Beams
Wolfe, R. W., and R. C. Moody.

1979. Bending strength of vertically glued laminated beams of one to five plies. USDA For. Serv. Res. Pap. FPL 333. For. Prod. Lab., Madison, Wis.

Lumber used for this study consisted of one grade of southern pine (No. 2D) from Louisiana and two grades of Douglas-fir (L1 and L3) from Oregon. Only those pieces having characteristics, typical of their respective grades, within the middle half of their length, were included. All lumber used was 12-foot long 2 by 6 dimension. Weight and MOE were determined using an E-computer and knots were measured using the displacement method.

Source 29: Shallow Beam Study I
Marx, C. M., and R. C. Moody.

1981. Bending strength of shallow glulam beams of a uniform grade. USDA For. Serv. Res. Pap. FPL 380. For. Prod. Lab., Madison, Wis.

Lumber for this study was collected and evaluated along with the lumber used in source 28. However, for this sample the length used was 14 feet rather than 12 feet.

Source 30: Shallow Beam Study II Marx, C. M., and R. C. Moody

1981. Strength and stiffness of small glued-laminated beams with different qualities of tension laminations. USDA For. Serv. Res. Pap. FPL 381. For. Prod. Lab., Madison, Wis.

The samples of 2 by 6 lumber included southern pine collected at a laminating plant in Arkansas on two different occasions, and Douglas-fir lumber from Oregon. The length of the southern pine lumber varied from 8 to 16 feet while the Douglas-fir ranged from 12 to 21 feet.

Lumber grades included AITC's 302-24 tension lamination (previously 301-24) for both species as well as No. 1D, No. 2D, and No. 2MG grade southern pine and L1, L2, L2D, and L3 grade Douglas-fir. For the tension lamination grades, efforts were made to select pieces of near-minimum quality.

MOE values were determined using the E computer and knot data are not included.

APPENDIX II

Tabulation of Knot and MOE Data

This appendix presents a summary of knot and modulus of elasticity data collected for seven species groups of lumber of potential value to the glulam industry. Tables II-1 and II-2 comprise the two major species groups, Douglas-fir and southern pine. Table II-3 presents limited data on visual grades of eastern spruce, Engelmann spruce, lodgepole pine, western hemlock, and hem-fir lumber. Tables II-4 to II-7 include Douglas-fir, southern pine, hem-fir, and lodgepole pine graded using MOE as one of the grading criteria.

In tables II-1 and II-2, sample sizes are given in terms of either number of pieces or lineal feet. Number of pieces refers to the sample size used to arrive at the knot data. Generally, when both values are given, the knot data were determined using only a portion of the pieces.

In tables II-4 to II-7, material is classified by three sets of numbers. The first number is the nominal MOE of the grade. This is followed by a dash and a nominal bending stress for the grade. A third number in parentheses follows which denotes the maximum edge knot size permitted in the grade, expressed as a fraction of the width.

Moisture content values were generally determined with either a resistance or power loss type of moisture meter at several locations along the length of the pieces and averaged. Specific gravity values are based on volume at time of test, and oven dry weight estimated from the moisture content.

Table II-1.—Modulus of elasticity and knot properties for visually graded Douglas-fir

		Sample size		Material properties				Modulus of elasticity: Measured		Modulus of elasticity: Adjusted to 12 percent moisture content		Knot properties		
Classification	Source	Pieces	Lineal feet	Nominal cross section	Moisture content	Specific gravity	Test method	Average	COV[1]	Average	COV[1]	Average	Near maximum	h_y[2]
					Pct			10^6 lb/in.^{2}	Pct	10^6 lb/in.^{2}	Pct	— — —	Pct	— —
LAMINATING GRADES														
	1		Unknown									6.8	36.3	29.5
	7	380	580	2 x 6	8.0	0.47	E-comp[3]	2.36	16.0	2.21	17.4	4.8	33.1	28.3
L1	7	150	450	2 x 10	8.2	.51	E-comp	2.27	15.8	2.13	17.1	4.4	26.8	22.3
	10		300	2 x 6								4.5	26.4	21.9
SL1	10		300	2 x 6								7.4	29.2	21.8
	17	181	600	2 x 6	11.0	.50	E-comp	2.23	15.9	2.19	16.9	6.0	38.2	32.2
L1	19	19	190	2 x 4	9.8	.50	E-comp	2.42	10.4	2.33	11.1	8.3	36.3	28.0
	20	42		2 x 6	12	.49	Tension	2.22	15.1	2.14	..			
	23		2,910	2 x 6								6.4	38.7	32.3
L1C	23		2,870	2 x 6								7.4	39.8	32.4
	25	254		2 x 6	11.7	.50	E-comp	2.34	14.4	2.33	15.4			
	27	134	450	2 x 4	12.0	.54	E-comp	2.33	20.1	2.34	21.2	4.3	35.0	30.7
L1	28	684	6,768	2 x 6	8.0	.49	E-comp					3.1	29.6	26.5
	29		960	2 x 6	9.2	.50	E-comp	2.33	16.6	2.22	17.4	4.6	31.8	27.3
	30	151		2 x 6	12	.49	E-comp	2.27	14.5	2.26	15.9			
	1		Unknown									10.4	43.3	29.9
L2	7	351	800	2 x 6	6.4	.44	E-comp	2.00	15.8	1.84	17.0	8.5	42.6	34.1
	7	97	360	2 x 10	6.6	.48	E-comp	1.98	14.4	1.82	15.5	7.8	39.9	32.1
	10		400	2 x 6								9.2	45.0	35.8
SL5	10		600	2 x 6								12.7	46.8	34.1

(Page 1 of 3)

Table II-1.—Modulus of elasticity and knot properties for visually graded Douglas-fir—con.

Classification	Source	Pieces	Lineal feet	Nominal cross section	Moisture content	Specific gravity	Test method	Modulus of elasticity: Measured: Average	COV[1]	Adjusted to 12 percent moisture content: Average	COV[1]	Knot properties: Average	Near maximum	R_k[1]
					Pct			10^6 lb/in.^{2}	Pct	10^6 lb/in.^{2}	Pct	– – –	Pct	– –
							LAMINATING GRADES—continued							
L2 Medium	11	121		2 x 6	11 4	46	E comp	1 99	13 4	1 98				
	17	334	1 700	2 x 6	9 9	46	E comp	1 83	16 3	1 77		9 6	54 1	42 5
	20	42		2 x 6	12	49	Tension	2 14	18 6	2 07				
	23		2,580	2 x 6								11 0	50.2	38 2
	27	90	900	2 x 4	10 1	49	E-comp	2 02	18.6	1 96	19 7	5 4	60 7	56 3
	30	115		2 x 6	10	43	E-comp	1 77	12 0	1 73	13.1			
L2 Dense	17	94	300	2 x 6	10.3	51		2.25	15.4	2 19		8 7	51 7	43
	19	38	380	2 x 4	9.8	49	E-comp	1 94	13.4	1 89	14.4	9 7	48.8	38 1
	23		2,960	2 x 6								9.5	46.7	37 2
	27	133	460	2 x 4				2 18	21 4	2 15	23.1	6.0	48 4	42 4
	30	73		2 x 6	12	.49	E-comp	2.02	13.8	2 02	14 8			
L3	1		Unknown									11 3	51 9	40 6
	7	604	1,380	2 x 6	5.8	.43	E-comp	1.71	16.7	1 56	17.9	11 6	56 1	43.5
	7	106	980	2 x 10	6.7	.47	E-comp	1.68	18.5	1 56	20 1	9.6	47 8	38.2
	10	--	700	2 x 6								11 2	63.2	52.0
	11	96		2 x 6	12.8	.44		1.80	14.2	1.63	14.9			
	17	91	400	2 x 6	11.3	.49	E-comp	1.83	16.0	1.81		11 1	68.6	57 5
	19	96	960	2 x 4	10.2	.47	E-comp	1.64	14.2	1.61	14 7	9.7	53.5	42.8
	23		2,940	2 x 6								11.6	58.0	46.4
	27	237	2,400	2 x 4	11.6	.51	E-comp	2.02	18.6	2.01	19 7	8.2	67 1	58.9
	28	504	6,816	2 x 6	8.3	.49	E-comp					6.3	50 7	44 4
	29	120	960	2 x 6	7.4	.50	E-comp	1.81	17 7	1.70	18.4	11 5	57 9	46 4
	30	260	--	2 x 6	11	.46	E-comp	1.68	18.0	1 66	20.6			
SL6	10	--	600	2 x 6								11.9	48.0	36 1

(Page 2 of 3)

Table II-1.—Modulus of elasticity and knot properties for visually graded Douglas-fir—con.

	Sample size			Material properties				Modulus of elasticity: Measured		Modulus of elasticity: Adjusted to 12 percent moisture content		Knot properties		
Classification	Source	Pieces	Lineal feet	Nominal cross section	Moisture content	Specific gravity	Test method	Average	COV[1]	Average	COV[1]	Average	Near maximum	h_v[2]
					Pct			10^6 lb/in.²	Pct	10^6 lb/in.²	Pct	---	Pct	--
JOISTS AND PLANK GRADES														
SS	20	46		2 x 6	12	49	Tension	2.27	17.2	2.23				
	24		4,153	2 x 6								5.6	38.3	30.7
No. 1	21		280	2 x 6								10.2	37.3	27.0
	24		4,207	2 x 6								9.8	47.1	37.3
No. 2	21		280	2 x 6								10.0	47.4	37.4
	24		4,280	2 x 6								10.8	51.6	40.7
No. 3	21		280	2 x 6								9.4	48.2	38.8
	24		4,180	2 x 6								10.4	58.7	48.3
TENSION LAMINATION GRADES														
301-87	7	15	100	2 x 6	8.6	52	E-comp	2.30	15.2	2.28	15.5	6.3	33.4	27.1
301 +	7	15	100	2 x 6	9.0	50	E-comp	2.66	11.1	2.54	12.3	3.2	21	17.8
	7	9		2 x 10	8.8	53	E-comp	2.38	12.3	2.28	13.8			
301-24	17	28	200	2 x 6	10.1	52	E-comp	2.28	15.5	2.25	15.7	3.9	34.2	30.3
301-20	17	27	200	2 x 6	10.6	51	E-comp	2.28	13.2	2.24	13.6	5.1	38.4	33.3
301A	20	41		2 x 6	12	53	Tension	2.44	18.0	2.44	18.0			
301B	20	41		2 x 6	12	52	Tension	2.54	10.7	2.54	10.7			
301-24	25	120		2 x 6	13	51	E-comp	2.41	12.9	2.46	12.9			
302-24	30	96		2 x 6	13	51	E-comp	2.50	14.0	2.54	15.3			
CANADIAN GRADES														
A	6	22		2 x 6	9.0	54	Tension	2.60	17.9	2.48	18.1			
BF	6	21		2 x 6	8.6	52	Tension	2.43	17.2	2.30	17.8			
B	6	36		2 x 6	8.5	52	Tension	2.47	14.5	2.34	14.9			
C	6	34		2 x 6	8.6	52	Tension	2.32	15.9	2.20	16.2			
D	6	36		2 x 6	8.4	48	Tension	1.91	18.7	1.80	19.2			

[1] COV = coefficient of variation (standard deviation divided by the mean).
[2] h_v = the difference between near maximum and average sum of knot sizes.
[3] E-comp = E-computer.

(Page 3 of 3)

Table B-2.—Modulus of elasticity and knot properties for visually graded southern pine

		Sample size		Material properties				Modulus of elasticity				Knot properties		
								Measured		Adjusted to 12 percent moisture content				
Classification	Source	Pieces	Lineal feet	Nominal cross section	Moisture content	Specific gravity	Test method[1]	Average	COV[2]	Average	COV[2]	Average	Near maximum	[illegible]
					Pct			10^6 lb/in.^{2}	Pct	10^6 lb/in.^{2}	Pct	- - -	Pct	- -
							LAMINATING GRADES							
No. 1D	1											2.6	[illegible]	[illegible]
	3	100		2 x 4	12.6	0.54	Flat	[illegible]	[illegible]	[illegible]				
							Edge	[illegible]	[illegible]	[illegible]				
	3	100		2 x 6	12.3	[illegible]	Flat	[illegible]	[illegible]	[illegible]				
							Edge	[illegible]	17.0	[illegible]				
	7	[illegible]		2 x 6	12.2	[illegible]	E-comp	2.01	[illegible]	[illegible]	[illegible]			
	7	[illegible]		2 x 10	[illegible]	[illegible]	E-comp	[illegible]	[illegible]	1.71	[illegible]			
	16	124	[illegible]	2 x 6	[illegible]	[illegible]	E-comp	[illegible]	17.0	[illegible]	-	[illegible]	41.3	[illegible]
	16		[illegible]	2 x 6								[illegible]	37.0	[illegible]
	28		[illegible]	2 x 6								3.2	31.6	[illegible]
	27	[illegible]		2 x 4	11	.47	E-comp	2.13	[illegible]	2.10				
	30	201		2 x 6	10	[illegible]	E-comp	1.70	[illegible]	1.75	[illegible]			
No. [illegible]	3	100		2 x 4	12.7	.54	Flat	[illegible]	[illegible]	[illegible]				
							Edge	[illegible]	[illegible]	[illegible]				
	3	100		2 x 4	12.7	[illegible]	Comp	[illegible]	17.0	[illegible]				
	3	100		2 x 6	12.4	[illegible]	Flat	[illegible]	[illegible]	[illegible]				
							Edge	[illegible]	[illegible]					
	3	[illegible]		2 x 6	[illegible]	[illegible]	Comp	[illegible]	[illegible]					
	7	34		2 x 6			E-comp	[illegible]	[illegible]	[illegible]	[illegible]			
	7	[illegible]		2 x 10			E-comp	[illegible]	31.1	2.13	31.3			
	16	101	[illegible]	2 x [illegible]	[illegible]	[illegible]	E-comp	1.70	[illegible]	1.70	[illegible]	[illegible]	[illegible]	[illegible]
	28		2,730	2 x 6								3.4	[illegible]	[illegible]
	27	16		2 x 4	11	[illegible]	E-comp	[illegible]	[illegible]	[illegible]	-			

(Page 1 of 4)

Table II-2.—Modulus of elasticity and knot properties for visually graded southern pine—con.

		Sample size		Material properties				Modulus of elasticity				Knot properties		
								Measured		Adjusted to 12 percent moisture content				
Classification	Source	Pieces	Lineal feet	Nominal cross section	Moisture content	Specific gravity	Test method	Average	COV[1]	Average	COV[1]	Average	Near maximum	I_K[2]
					Pct			10^6 lb/in.^{2}	Pct	10^6 lb/in.^{2}	Pct	– – –	Pct	– –
					LAMINATING GRADES—continued									
	1											5.5	44.7	39.8
	3	100		2 x 4	12.5	.53	Flat	1.69	19.0	1.70	—			
							Edge	1.67	19.0	1.68	—			
	3	100		2 x 8	12.3	.53	Flat	1.70	19.0	1.71	—			
							Edge	1.71	19.0	1.72	—			
	4	96		2 x 4	12.2	.52	Tension	1.73	23.9	1.74	23.9			
							Flat	1.71	21.9	1.71	22.0			
	4	40		2 x 6	12.2	.53	Tension	1.77	19.0	1.78	19.1			
							Flat	1.70	16.9	1.71	17.1			
	4	40		2 x 8	12.2	.51	Tension	1.56	20.9	1.57	21.0			
No. 2D							Flat	1.59	19.6	1.60	19.7			
	5	100		2 x 4	12.0	.54	Flat	1.82	18.6	1.82	18.6			
	5	100		2 x 8	11.8	.54	Flat	1.81	19.3	1.81	19.8			
	7	442	600	2 x 6	12.3	.57	E-comp	1.83	16.7	1.84	17.5	8.5	50.4	41.8
	7	126	270	2 x 10	12.5	.49	E-comp	1.63	18.5	1.65	18.1	6.5	39.5	33.1
	10		200	2 x 6								5.3	38.0	30.7
	16	168	200	2 x 6	11.1	.53	E-comp	1.77	21.6	1.74		10.0	61.0	51.0
	23		2,620	2 x 6								8.1	52.0	43.9
	28	512	6,168	2 x 6	11.3	.54	E-comp	1.73	18.4	1.72	18.3	5.8	52.0	46.0
	29	119	962	2 x 6	9.6	.68	E-comp	1.75	16.0	1.69	16.0	9.3	53.4	44.1
	30	174		2 x 6	10.0	.52	E-comp	1.72	21.8	1.67	22.7			
	3	100		2 x 4	12.5	.51	Flat	1.56	19.0	1.56	—			
							Edge	1.54	19.0	1.56	—			
	3	100		2 x 4	12.6	.50	Comp	1.56	22.0	1.58	—			
	3	100		2 x 6	11.4	.52	Flat	1.60	18.0	1.58	—			
No. 2							Edge	1.62	17.0	1.60	—			
	3	90		2 x 6	11.8	.51	Comp	1.63	23.0	1.62	—			
	3	100		2 x 8	12.3	.52	Flat	1.59	18.0	1.60	—			
							Edge	1.63	20.0	1.64	—			
	3	48		2 x 8	11.0	.52	Comp	1.56	22.0	1.53	—			
	11	167		2 x 6	8.2	.49	E-comp	2.11	16.2	2.00	—			

(Page 2 of 4)

Table II-2.—Modulus of elasticity and knot properties for visually graded southern pine—con.

Classification	Source	Sample size: Pieces	Sample size: Lineal feet	Material properties: Nominal cross section	Material properties: Moisture content	Material properties: Specific gravity	Test method	Modulus of elasticity, Measured: Average	Modulus of elasticity, Measured: COV[1]	Modulus of elasticity, Adjusted to 12 percent moisture content: Average	Modulus of elasticity, Adjusted to 12 percent moisture content: COV[1]	Knot properties: Average	Knot properties: Near maximum	Knot properties: b_y^2
					Pct			10^6 lb/in.^{2}	Pct	10^6 lb/in.^{2}	Pct	– – –	Pct	– –
							LAMINATING GRADES—continued							
No. 2MG	7	367	2,220	2 x 6	13.1	.46	E-comp	1.49	15.2	1.47	16.0	10.9	55.5	44.6
	7	85	1,530	2 x 10	12.3	.51	E-comp	1.44	16.5	1.48	19.2	6.3	40.9	34.8
	10		1,400	2 x 6								6.3	46.2	38.9
	11	136		2 x 6	12	.52	E-comp	1.80	9.0	1.80	9.0			
	16	320	800	2 x 6	10.1	.49	E-comp	1.50	18.6	1.46		9.3	56.0	46.7
	16		4,160	2 x 6								9.0	56.5	47.5
	23		2,600	2 x 6								7.7	43.4	36.7
	27	180	900	2 x 4	10.4	.41	E-comp	1.53	17.8	1.49		8.6	57.7	49.1
	30	1,086		2 x 6	9	.48	E-comp	1.40	19.1	1.33	19.7			
No. 2CG	16	488	2,400	2 x 6	9.8	.45	E-comp	1.11	22.0	1.07	—	9.7	57.8	48.1
No. 3	1											9.3	68.7	57.4
	3	100		2 x 4	12.3	.52	Flat	1.43	29.0	1.44	—			
							Edge	1.40	29.0	1.41	—			
	3	100		2 x 4	11.8	.52	Comp	1.48	25.0	1.48	—			
	3	100		2 x 8	12.1	.49	Flat	1.17	25.0	1.17	—			
							Edge	1.29	28.0	1.29	—			
	3	50		2 x 8	10.7	.53	Comp	1.45	21.0	1.42	—			
	7	88		2 x 6	12.3	.51	E-comp	1.46	23.3	1.46	25.0			
	4	96		2 x 4	11.9	.51	Flat	1.54	25.3	1.54	25.3			
							Tension	1.46	18.1	1.46	18.3			
No. 3MG	4	49		2 x 8	12.4	.52	Flat	1.58	23.8	1.59	23.9			
							Tension	1.51	27.5	1.53	27.6			
	11	135		2 x 6		.49	E-comp	1.86	20.0	1.71	20.0			
No. 3CG	16	435	2,400	2 x 6	9.6	.46	E-comp	1.23	19.2	1.18	—	10.8	66.1	56.3

(Page 3 of 4)

Table II-2.—Modulus of elasticity and knot properties for visually graded southern pine—con.

Classification	Sample size: Source	Sample size: Pieces	Sample size: Lineal feet	Material properties: Nominal cross section	Material properties: Moisture content	Material properties: Specific gravity	Test method	Modulus of elasticity: Measured: Average	Measured: COV[1]	Adjusted to 12 percent moisture content: Average	Adjusted: COV[1]	Knot properties: Average	Knot properties: Near maximum	Knot properties: h_y[2]
					Pct			10^6 lb/in.^{2}	Pct	10^6 lb/in.^{2}	Pct	– – –	Pct	– –
TENSION LAMINATING GRADES														
301 +	7	9	128	2 x 6	12.0	.51	Tension	1.89	10.2	1.89	11.8	7.0	43.1	36.1
301	9	6		2 x 6	12.5	.56	Tension	2.19	11.2	2.20	10.8			
301-PA	9	36		2 x 6	12.1	.51	Tension	1.74	15.1	1.74	14.4			
301 +	9	41		2 x 6	12.1	.56	Tension	2.17	18.3	2.18	18.8			
301 + P	9	21		2 x 6	12.0	.52	Tension	2.00	16.3	2.00	15.9			
301-67	7	14		2 x 6	12.14	.56	Tension	2.14	12.2	2.15	12.3			
	7	15		2 x 10	10.73	.53	Tension	2.16	10.7	2.17	12.0			
301-20	16	26	200	2 x 6	11.0	.51	Tension	1.78	23.4	1.75	24.2	6.3	49.1	42.8
	16	27	200	2 x 6	11.8	.56	Tension	2.11	18.5	2.15	19.6	4.2	30.6	26.4
301-24	18		280	2 x 6								2.3	29.1	26.8
	30	276		2 x 6	10	.54	E-comp	1.96	16.4	1.93	17.1			

[1] COV = coefficient of variation (standard deviation divided by the mean).
[2] h_y = the difference between near maximum and average sum of knot sizes.
[3] E-comp = E-computer, Flat and Edge refer to static bending test and comp = compression test.

(Page 4 of 4)

Table II-3.—Modulus of elasticity and knot properties for other species of visually graded lumber

Classification	Sample size: Source	Sample size: Pieces	Sample size: Lineal feet	Material properties: Nominal cross section	Material properties: Moisture content	Material properties: Specific gravity	Test method	Modulus of elasticity: Measured: Average	Measured: COV[1]	Adjusted to 12 percent moisture content: Average	Adjusted: COV[1]	Knot properties: Average	Knot properties: Near maximum	Knot properties: h_y[2]
					Pct			10^6 lb/in.^{2}	Pct	10^6 lb/in.^{2}	Pct	– – –	Pct	– –
ENGELMANN SPRUCE														
L3	27	163	300	2 x 4	12.4	0.40	E-comp	1.20	14.9	1.21	15.4	16.0	61.4	45.4
N3	27	342		2 x 4	10.3	.39	E-comp	1.22	17.0	1.19	17.5			
EASTERN SPRUCE														
SS	15		2,400	2 x 6								8.2	40.2	32.0
N1	15		2,566	2 x 6								13.9	47.4	33.5
N2	15		2,566	2 x 6								15.9	53.6	37.7
LODGEPOLE PINE														
L3	14		1,180	2 x 6								23.0	78.8	56.8
L3	17	604	3,000	2 x 6	10.3	.43	E-comp[3]	1.11	23.1	[4]1.08	—	20.6	83.5	62.9
HEM-FIR														
L1	13	25	600	2 x 6			E-comp	1.98	16.3	1.84	—			
L1	27	14		2 x 4	10.0	.39	E-comp	1.56	14.0	1.50	14.0			
L1 Dense	27	63	180	2 x 4	10.2	.39	E-comp	1.64	12.0	1.59	12.2	11.2	49.3	38.1

(Page 1 of 2)

Table II-3.—Modulus of elasticity and knot properties for other species of visually graded lumber—con.

	Sample size			Material properties				Modulus of elasticity				Knot properties		
								Measured		Adjusted to 12 percent moisture content				
Classification	Source	Pieces	Lineal feet	Nominal cross section	Moisture content	Specific gravity	Test method	Average	COV[1]	Average	COV[1]	Average	Near maximum	h_v[2]
					Pct			10^6 lb/in.²	Pct	10^6 lb/in.²	Pct	– – –	Pct	– –
							HEM-FIR—continued							
L2	13	60	1,000	2 x 6			E-comp	1.74	17.4	1.62	—			
L2	27	92	460	2 x 4	9.0	.36	E-comp	1.27	14.6	1.21	15.4	11.1	61.4	50.3
L3	13	140	1,300	2 x 6			E-comp	1.72	19.6	1.63	—			
L3	27	273	1,600	2 x 4	9.0	.36	E-comp	1.20	14.8	1.15	15.1	13.0	67.1	54.1
							CANADIAN WESTERN HEMLOCK							
A	2		542	2 x 6								2.3	16.5	14.2
A	2		612	2 x 10								2.1	11.0	8.9
B	2		593	2 x 6								8.1	32.0	24.0
B	2		606	2 x 10								6.2	26.6	20.4
C	2		606	2 x 6								10.4	48.2	37.8
C	2		647	2 x 10								9.6	38.2	28.6
D	2		547	2 x 6								13.0	60.9	47.9
D	2		671	2 x 10								10.1	44.6	34.4

[1] COV = coefficient of variation (standard deviation divided by the mean).
[2] h_v = the difference between near maximum and average sum of knot sizes.
[3] E-comp = E-computer.
[4] Adjusted MOE based on average MC rather than individual values.

(Page 2 of 2)

Table II-4.—Knot properties for E-rated grades of Douglas-fir

Classification	Source	Sample size: Lineal feet	Nominal cross section	Knot properties: Average	Near maximum	h_v[1]
				---------- Pct ----------		
1.4 − (1/2)	8 + 12	1,820	2 x 6	12.4	59.4	47.1
1.8 − 900 (1/2)	8 + 12	840	2 x 6	14.2	62.6	48.3
2.0 − 900 (1/2)	8 + 12	920	2 x 6	10.0	46.6	36.7
2.4 − 900 (1/2)	8 + 12	240	2 x 6	10.1	51.4	41.4
	27	300	2 x 4	9.7	68.6	58.8
1.6 − 1800 (1/4)	8 + 12	240	2 x 6	17.0	60.9	43.9
2.4 & 2.6 − 1800 (1/4)	8 + 12	1,120	2 x 6	4.3	30.9	26.6
1.8 − 2100 (1/6)	8 + 12	240	2 x 6	7.0	46.4	39.4
2.0 − 2400 (1/6)	8 + 12	480	2 x 6	8.6	42.7	34.2
	27	300	2 x 4	8.4	45.0	36.6
2.2 − 2700 (1/6)	8 + 12	480	2 x 6	5.2	37.8	32.6
	27	300	2 x 4	6.3	42.8	36.5
2.4 − 3000 (1/6)	8 + 12	240	2 x 6	4.2	30.0	25.8
2.6 − 3300 (1/6)	8 + 12	880	2 x 6	4.3	31.1	26.8

[1] h_v = the difference between near maximum and average sum of knot sizes.

Table II-5.—Knot properties for E-rated grades of southern pine

Classification	Source	Sample size: Lineal feet	Nominal cross section	Knot properties: Average	Near maximum	h_v[1]
				---------- Pct ----------		
1.2 − 900 (1/2)	12	320	2 x 6	11.1	69.8	58.7
1.8 − 900 (1/2)	12	480	2 x 6	10.4	75.3	64.9
	27	300	2 x 4	9.4	58.6	49.1
2.0 − 900 (1/2)	12	240	2 x 6	9.4	74.6	65.1
2.2 − 900 (1/2)	12	240	2 x 6	7.1	58.4	51.3
1.8 − 2100 (1/6)	27	300	2 x 4	5.8	47.3	41.5
1.8 − 2200 (1/6)	12	480	2 x 6	8.9	67.6	58.7
2.0 − 2400 (1/6)	27	300	2 x 4	2.4	21.8	19.4
2.0 − 2500 (1/6)	12	240	2 x 6	3.8	36.4	32.6
2.2 − 2800 (1/6)	12	240	2 x 6	3.5	40.9	37.4

[1] h_v = the difference between near maximum and average sum of knot sizes.

Table II-6.—Knot properties for E-rated grades of hem-fir

Classification	Source	Sample size: Pieces	Sample size: Lineal feet	Nominal cross section	Knot properties: Average	Knot properties: Near maximum	Knot properties: h_v[1]
					Pct	Pct	Pct
1.3 – 900 (1/2)	8 + 12		320	2 x 6	11.6	54.9	43.3
1.5 – 900 (1/2)	8 + 12		240	2 x 6	6.7	41.3	34.6
	26	100	1,568	2 x 6	8.8	48.2	39.4
1.8 – 900 (1/2)	8 + 12		1,200	2 x 6	4.7	34.2	29.5
	26	100	1,440	2 x 6	9.9	62.6	52.7
	27		300	2 x 4	6.0	42.7	36.7
1.4 – 1800 (1/4)	8 + 12		1,680	2 x 6	7.9	49.6	41.7
1.5 – 1650 (1/4)	26	100	1,520	2 x 6	5.5	36.6	31.1
1.5 – 1800 (1/4)	8 + 12		240	2 x 6	2.6	32.2	29.6
1.6 – 1800 (1/4)	8 + 12		240	2 x 6	7.2	36.9	29.7
1.8 – 1800 (1/4)	8 + 12		480	2 x 6	4.4	36.7	32.3
1.8 – 2100 (1/6)	8 + 12		1,200	2 x 6	3.7	31.1	27.5
	22	31	496	2 x 6	6.7	33.4	26.7
	26	100	1,440	2 x 6	6.0	42.7	36.7
	27		150	2 x 4	5.6	41.0	35.4
2.0 – 900 (1/2)	8 + 12		1,200	2 x 6	4.7	34.2	29.5
2.0 – 2400 (1/6)	8 + 12		1,420	2 x 6	3.2	29.4	26.2
	22	31	496	2 x 6	5.2	30.6	25.4
	27		150	2 x 4	5.4	29.3	23.9

[1] h_v = the difference between near maximum and average sum of knot sizes.

Table II-7.—Knot properties for E-rated grades of lodgepole pine

Classification	Source	Sample size: Lineal feet	Nominal cross section	Knot properties: Average	Knot properties: Near maximum	Knot properties: h_v[1]
				Pct	Pct	Pct
1.3 – 900 (1/2)	8 + 12	240	2 x 6	16.0	57.8	41.8
1.5 – 900 (1/2)	8 + 12	480	2 x 6	14.8	56.6	41.8
	27	300	2 x 4	17.3	71.4	54.1
1.7 – 900 (1/2)	8 + 12	240	2 x 6	14.5	63.6	49.1
1.3 – 1450 (1/3)	8 + 12	240	2 x 6	18.1	60.4	42.2
1.5 – 1450 (1/3)	8 + 12	480	2 x 6	13.3	51.3	38.0
1.5 – 1650 (1/3)	27	150	2 x 4	11.8	47.1	35.3
1.7 – 2050 (1/4)	8 + 12	240	2 x 6	9.8	53.3	43.4
1.8 – 2100 (1/6)	27	150	2 x 4	11.4	45.7	34.3

[1] h_v = the difference between near maximum and average sum of knot sizes.

2.5-21-8/81

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981/730-027/10

LME